Path instabilities of heavy bodies in free fall in a viscous fluid: wake dynamics vs. aerodynamic effects

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Solid bodies in free fall in a viscous fluid generally fall along a non-straight path, and a variety of periodic (fluttering, tumbling) and non-periodic regimes can be observed [Ern et al., ARFM 2012 ; Auguste et al. JFM 2013]. In general, the problem is characterized by a strong coupling between the body and the surrounding fluid, so it is hard to disentangle the contributions of wake dynamics (loads exerted on the body due to periodic vortex shedding) from those of aerodynamic effects (loads resulting from the body's inclination, rotation, etc...). In this presentation, we analyze the structure of the couplings in the case of heavy bodies, restricting ourselves to a linear stability framework. Introducing a simple toy model consisting of a infinitely long plate sliding along a vertical wall, we show that in the limit of large solid-to-fluid masses a decoupling takes place, allowing us to distinguish two kinds of modes: "wake" modes in which the body motion has virtually no influence, and "body" modes for which the intrinsic wake dynamics can be neglected. Turning to more realistic 2D and 3D bodies, we show that the "body" modes can be described through a rationally derived quasi-static model (in which all forces are expressed in terms of the body's degrees of freedom), and demonstrate that such a model predicts two different kinds of instabilities: a quasi-static instability, and a dynamic, low-frequency, instability.

We apply these ideas to the cases of 2D rods of rectangular section and 3D disks and identify, for these geometries, the range of existence of the "wake" instability, "quasi-static body" instability and "dynamic body" instability, as function of the body's aspect ratio and Reynolds number (up to Re = 300). It is found that for 2D bodies the "wake" instability dominates, while for 3D disks, the "dynamic body" instability dominates.